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Should We Invest in Martian Brine Research to Reduce Mars Exploration Costs?

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SINCE PUBLICATION OF the first evidence of liquid water on present-day Mars (Martín-Torres *et al.*, 2015) according to Curiosity data, scientists have wondered how best to further investigate the presence of brines. Initial evidence was acquired at Gale Crater, near the equator of the planet, a location where this presence of liquid water was highly unexpected. This evidence was later corroborated by the detection of spectral evidence for hydrated salts in martian recurring slope lineae by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) instrument on board the Mars Reconnaissance Orbiter (Ohja *et al.*, 2015).

Such findings have opened a new frontier of exciting scientific challenges. The spatial and temporal distribution of transient liquid water on Mars has wide implications for our understanding of the availability and history of water on Mars, the plausible preservation of organics, the corrosive interaction of these brines with spacecraft materials, and other geological water-related and climate processes on present-day Mars. Most importantly, however, the presence of liquid water on Mars has enormous implications for planetary protection and planetary protection policies. The mission of NASA's Office of Planetary Protection is to protect the study of Solar System bodies—including planets, moons, comets, and asteroids—from contamination by Earth life and to protect Earth from possible life-forms that may be returned from other Solar System bodies (NASA, 2016a).

Since April 2015, the direction of the strategy of NASA's Mars exploration has changed. In particular, on June 24, nearly 4 years after the landing of the rover Curiosity on Mars, NASA published its intention to use the rover to image potential Mars water sites (NASA, 2016b) to detect brine signatures at Gale Crater. Though for many this might have been a prime goal from the beginning of the Mars Science Laboratory mission, NASA's decision to change strategy now renews hope of finding liquid water at the martian surface. However, plans for such a search elicit a call for extreme caution.

Ironically, the presence of water is a complication for the operation of any surface spacecraft as well as for the search for life. The reason for this is that regions where water is available are potentially more favorable for Earth life to survive, and we do not want to contaminate Mars with Earth life-forms that are brought within the spacecraft. We do not want to discover life on Mars and later realize that this life is a contamination from Earth, which would indicate a ''false positive''. If there are brines on the surface or near the subsurface of Mars, how can we search for evidence of life without contaminating these sites with microorganisms from Earth? The presence of brines on Mars raises a new question: How close could a robotic spacecraft, such as Curiosity, safely investigate a region with brines? The scientific value of such an investigation aside, the detection of liquid water in the form of brines would have impacts from operational, economical, and political points of view in the Mars Exploration Program.

From an operational point of view, interaction between the operation team of a robotic spacecraft and planetary protection offices of various space agencies would be more important than ever, and discussions would need to take place as soon as the scientific community acquired any plausible evidence of frost, ice, seasonal or diurnal morphological changes, flowlike structures, biomarker detections (*e.g.*, methane), salt deposits detectable by visual inspection of images, and of course any liquid water–related observation.

1. The Golden Age of Mars Exploration

Mars exploration has bloomed as one of the most important targets of scientific-technical and strategic (nonmilitary) international interest. The Curiosity rover journeys on with a healthy payload and much left to explore. After the very recent examination of a large, active dune field, the rover will, over the course of the next few years, traverse an extensive ridge enriched in iron oxide; explore a region on Aeolis Mons where orbiting satellites have detected clay minerals; and ascend the slopes of Aeolis Mons until it reaches a layer where sulfate minerals are present, perhaps signifying a more sulfur-rich and arid environment when

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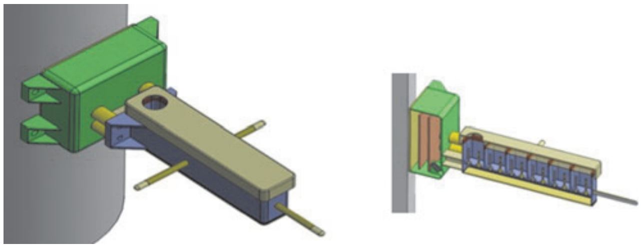

FIG. 1. Sketch of the HABIT instrument to fly on board ESA's ExoMars 2020, and cross-section view of the containers for brine production.

these materials formed. The mission has been successfully operating to date, and on July 1, 2016, based upon the 2016 Planetary Mission Senior Review Panel report (NASA Science Mission Directorate, 2016), NASA directed Curiosity and eight other extended missions to plan for continued operations through the fiscal years 2017 and 2018. In addition to this extraordinary exploration effort, NASA will launch a new rover for Mars exploration in 2020.

Mars exploration is also the focus of ESA and of Russia's Roscosmos with the launch of the Trace Gas Orbiter (TGO) and the Schiaparelli Entry, Descent, and Landing Demonstrator Module on March 14, 2016, and in 2020 the launch of the ExoMars rover and surface platform. On October 19, 2016, the TGO successfully inserted itself into orbit around Mars, though the Schiaparelli lander failed the attempt to land on the planet. ESA is also interested in detailed investigation of the present water cycle on Mars. In November 2015, ESA approved the selection of the instrument HABIT (Habit-Ability, Brines, Irradiation, and Temperature) to be part of the ExoMars Surface Platform, which will travel to Mars in 2020 (ESA, 2016). Two of the main goals of HABIT (see Fig. 1) are (1) to study the water cycle on Mars by simulating in a controlled way the brine formation process and (2) to develop a prototype of In Situ Resource Utilization (ISRU), designed to produce liquid water from martian atmospheric water vapor that can be used in robotic exploration. A larger ISRU prototype could be employed on future missions to supply water for astronauts and martian greenhouses. HABIT will facilitate the search for habitable environments by providing environmental context for sample collection, and it will further search for evidence of liquid water and inform with regard to planetary protection policies.

The noted missions aside, the Mars Odyssey, Mars Express, Mars Exploration Rovers, and Mars Reconnaissance Orbiter are still sending data from Mars, and as of September 2014, the NASA Mars Atmosphere and Volatile EvolutioN (MAVEN) mission has been in orbit around Mars. Also, in September 2014, the Indian Space Research Organization (ISRO) successfully placed in orbit the Mars Orbiter Mission (MOM), making it the fourth space agency to reach Mars. Discoveries continue to be made.

It would seem that we live in the Golden Age of Mars exploration, and until now *in situ* and satellite missions to Mars have extensively investigated clues for ancient water-rich environments. The search for indications of water in Mars' past, still a very interesting topic, has been joined by an increasing interest in the search for signatures of extant water on Mars in the form of brines and their impact on the water cycle (see Fig. 2).

For the first time, space agencies have begun to consider extant water on Mars and its implications for future Mars exploration. The presence of water, at the surface and in the subsurface, may one day provide the capacity for the production of H_2 and O_2 on Mars in an efficient, self-sustained manner. Such an occurrence would be critical to the viability of sample return missions and to human exploration of Mars.

2. Special Region Definition

The international collaboration between space agencies that are involved with Mars exploration should be encouraged with the intent to define a common framework of exploration.

The cost of a mission to Mars can substantially increase if a designated landing site is deemed by the Office of Planetary Protection to be a region where Earth life could theoretically survive (Fairén and Schulze-Makuch, 2013).

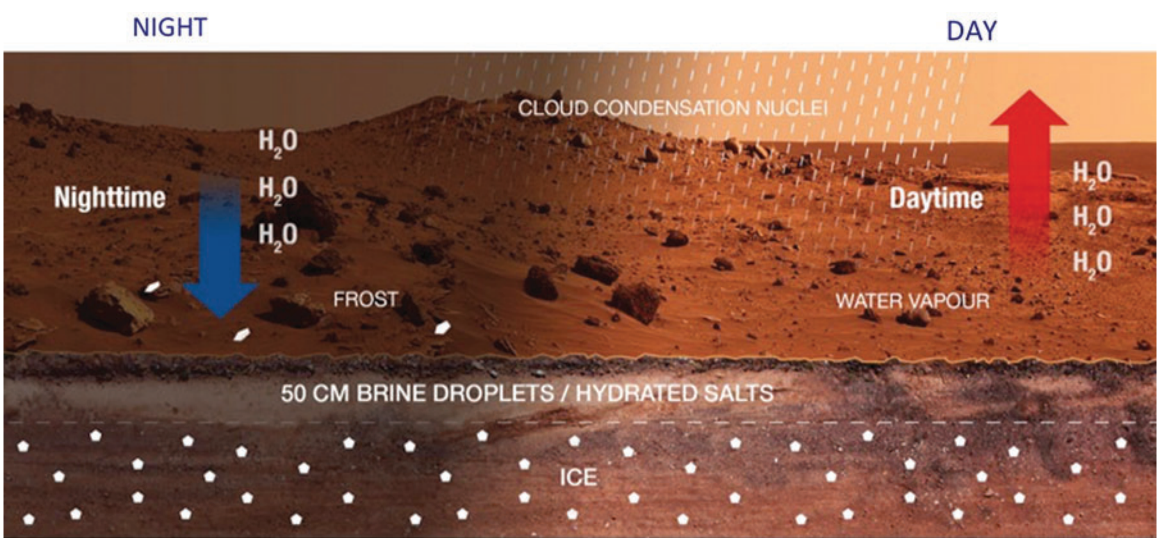

FIG. 2. The water cycle on Mars. Infographic representation of the present-day water cycle on Mars and the atmosphere–regolith water interchange. Here the diurnal cycle is represented for a low-latitude region.

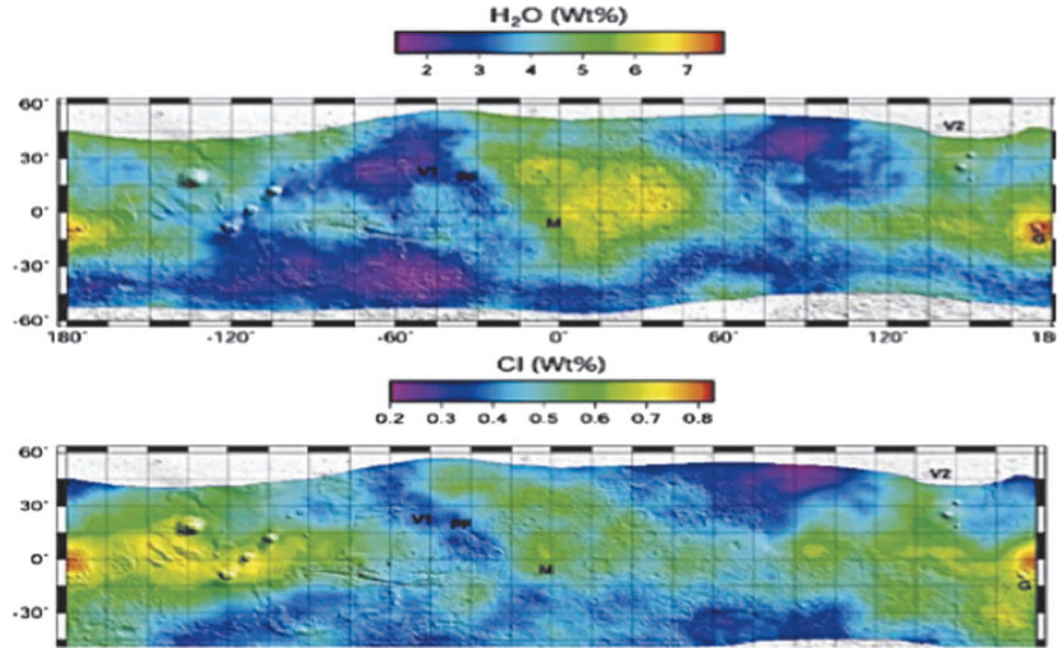

FIG. 3. Equatorial and midlatitude distribution of soil equivalent-water distribution and chlorine within the top 1 m of Mars as detected by NASA's Mars Odyssey GRS. (*Image credit*: NASA/JPL/University of Arizona; Keller *et al.*, 2006; Feldman *et al.*, 2004).

These regions are called ''Special Regions'' (Rummel *et al.*, 2014), and although they can be the most interesting regions to explore in the search for evidence of martian life, missions that target these areas are required to comply with very expensive sterilization procedures to prevent contamination of the planet. The definition of ''Special Region'' should be agreed upon by all space agencies involved, as these localities present numerous opportunities for planetary research (Rettberg *et al.*, 2016).

Brines are produced under specific environmental conditions in the daily capture (and release) of atmospheric water vapor by deliquescent salts that exist at the surface of Mars, such as chlorides (Cl^-) and perchlorates (ClO_4^-). These salts were detected by Phoenix in the north polar plains and by the Mars Science Laboratory Curiosity at Gale Crater. The perchlorates found *in situ* are likely calcium perchlorate as detected by Curiosity at Gale (Leshin *et al.*, 2013; Ming *et al.*, 2014) and magnesium or sodium perchlorates as observed at the Phoenix polar landing site (Hecht *et al.*, 2009). Reanalysis of Viking data suggests that perchlorates could have been present there as well (Navarro-González *et al.*, 2010). Chlorine is distributed globally on Mars as detected by the Mars Odyssey Gamma Ray Spectrometer (GRS) (Keller *et al.*, 2006; Feldman *et al.*, 2004; see Figure 3). Oxygen was one of the most abundant gases released during thermal analysis of materials at Curiosity's Rocknest site, and its release was correlated with the release of chlorinated hydrocarbons (Archer *et al.*, 2014). This O_2/Cl correlation makes a strong case for the presence of chlorine in the form of perchlorates.

Sulfate and chloride salts have been detected on rocks and in the soils of the Meridiani and Gusev sites by the Alpha Particle X-ray Spectrometer (APXS) instrument on the Mars Exploration Rovers (Clark *et al.*, 2005; Campbell *et al.*, 2008; Schmidt *et al.*, 2008); chlorides have also been detected on the southern hemisphere by the Thermal Emission Imaging System (THEMIS) instrument on the Mars Odyssey orbiter (Osterloo *et al.*, 2010). Some of these superficial chloride salt deposits, such as those found in a crater in Terra Cimmeria, extend over a region of approximately 900 m^2.

The global presence of chlorine and the detection of perchlorate at two very different latitudes (Phoenix and Curiosity landing sites) may support the hypothesis that perchlorates are globally distributed in the regolith of Mars. The orbiter signals show coincidence of the Cl and H signal over the map of Mars (Fig. 3). If perchlorates are at shallow depths that interact with exchangeable atmospheric water, as suggested by the detection of Cl and H by the pulsing neutron generator called the Dynamic Albedo of Neutrons (DAN), then there may be a planet-wide water reservoir (Martín-Torres *et al.*, 2015). Nevertheless, evidence of brines on Mars, to date, has been found under conditions where water activity and temperature are probably too low to support terrestrial organisms (Martín-Torres *et al.*, 2015).

Table 1. Suggested Topics of Research

- Map, using observations and models, the potential locations where brines may be naturally formed on Mars, including surface and subsurface.
- Investigate the habitability of martian brines using laboratory experiments, field site studies, Mars environmental chambers, and microbiological studies on metabolic and reproduction rates.
- Map regions where water can be artificially extracted either from the subsurface or the atmosphere.
- Determine best sites for human Mars exploration on Mars, and compare with surface-based observations of previous missions.
- Design ISRU technologies that can efficiently capture critical elements like H_2, O_2, H_2O anywhere on the planet.

At this juncture in the exploration of Mars, investigators will need to address questions as to how the discovery of liquid water on Mars will affect future Mars missions. If brines are found to be distributed across the planet, which would expand the terrain designated as Special Regions on Mars, then the cost of future Mars missions may increase significantly due to the need to apply more stringent planetary protection protocols to mission and instrument designs. An investment in studies on the location of martian brines and their habitability potential could provide additional information that would lower the cost of the mission within the Mars Exploration Program.

Further, an International Roadmap for Mars Exploration is needed. Table 1 summarizes a list of desirable research topics that should be strongly pursued in order to understand the impact of the presence of brines and their habitability on the Mars Exploration Program. We should be able to answer those questions that have to do with when and where brines exist on Mars, and the potential that they are habitable. The presence of transient liquid water needs to be included in Mars water cycle studies; currently, the temporal windows of time and the geographical locations where brines may be transiently stable are unknown. The phase diagrams of salts in interaction with atmospheric water under martian pressures and non-equilibrium conditions for mixtures of salts should be revised in particular with regard to the time response of efflorescence and deliquescence. Analysis of implications for planetary protection, habitability, and human exploration should be conducted. An outcome of the research topics in Table 1 will most likely lead to a redefinition of the Special Region concept at the surface and near-subsurface.

Human exploration has always been driven by the desire to explore the unknown, and as a by-product of this natural human impulse for exploration there have been enormous advancements in technological, intellectual, and philosophical developments that have worked to configured humankind as we know it today. The discovery of a large deposit produced by brines on Mars could hold the key to further human exploration or even colonization of the Red Planet.

The question then is, are we ready for the next exploration impulse? And from a political and operational point of view it must be asked, in what ways would the discovery of brines on Mars help steer our exploration efforts? In what ways would it hinder our control over Mars contamination? And if we were to colonize Mars, can we do so without further contaminating the planet?

Understanding the presence and habitability of brines on Mars is vital to assess the planet's potential for harboring life and for providing usable resources for future human exploration. Already there have been studies of the thermodynamic stability of salt (NaCl) solutions on Mars (Lobitz *et al.*, 2001). The search for martian brines will be a trending topic for decades to come, the search for the new gold of Mars.

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Abbreviations Used

GRS = Gamma Ray Spectrometer
HABIT = HabitAbility, Brines, Irradiation, and Temperature
ISRU = In Situ Resource Utilization
TGO = Trace Gas Orbiter